SD Numerical Simulation Technique for Hydrodynamic Flow Gas-Solids Mixing

Presented by:

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Abstract

We formulate a new mathematical model for a combustion chamber hydrodynamic fluid bed system (CFB) in thermal coal or solid waste power plants.

This mixture model is based in conservation equations (mass and momentum). This model gas - solid is obtained from two-phase hydrodinamic model, which takes into account a parameter ε (ratio densities gas/solid), it generates a free boundary problem.

Making an asymptotic adjustment and uncoupling of the dependent variables, then this problem has solution. The numerical simulation in 2D is implemented with COMSOL Multiphysics.

Content

- 1. Problem Formulation
- 2. Theoretical Analysis-Contribution
- 3. Numerical Resolution: Using COMSOL MULTIPHYSIC
- 4. Results

INTRODUCTION SQUEME SYSTEM CFB [6]



1. Problem Formulation

Antecedent: The interphase momentum transfer between the two phases represented by the drag force, play an important role in any multiphase flow approach. Due to its high relevance, this phenomenon was frequently investigated in the literature. The ultimate goal of these work was to get an optinum drag model for betters fluidized bed hydrodynamics.

The volume fractions conservation equations are related as:

$$\mathcal{E}_s + \mathcal{E}_g = \mathbf{I}$$

Equations two phases of Gidaspow, Syamlal & O'Brien

• Mass conservation equations

 $\frac{\frac{\partial(\varepsilon_{g}\rho_{g})}{\partial t} + \nabla (\varepsilon_{g}\rho_{g}u_{g}) = 0}{\frac{\partial(\varepsilon_{s}\rho_{s})}{\partial t} + \nabla (\varepsilon_{s}\rho_{s}u_{s}) = 0}$

• Momentum conservation equations

$$\frac{\partial(\varepsilon_{g}\rho_{g}u_{g})}{\partial t} + \nabla (\varepsilon_{g}\rho_{g}u_{g}u_{g}) = \nabla (\tau_{g}) - \varepsilon_{g}\nabla P - \beta(u_{g}-u_{s}) + \varepsilon_{g}\rho_{g}g$$

$$\frac{\partial(\varepsilon_{s}\rho_{s}u_{s})}{\partial t} + \nabla (\varepsilon_{s}\rho_{s}u_{s}u_{s}) = \nabla (\tau_{s}) - \varepsilon_{s}\nabla P - \nabla P_{s} - \beta(u_{g}-u_{s}) + \varepsilon_{s}\rho_{s}g$$

The simulation results showed that the drag models of Gidaspow and Syamlal & O'Brien highly overestimate the gassolid drag force for the CFB the particles could not predict the formation of dense phase in the fluidized bed [2].

The conditions are characteristic of fast fluidization [1], [4]



A gas injection grid of Chamber CFB



Grid of pipes

Inlet

Two Phases Model Drew [2]

- Phase Gas:
- $\partial_t n + div(nu) = 0$ (1)
- $\partial_t(nu) + div(nu \otimes u + p_g I) = div(2v_g nD(u)) + ng qm(u v)$ (2)
- Phase Particle
- $\partial_t m + div(mu) = 0$ (3)
- $\partial_t(mv) + div(mv \otimes v + p_p I) = div(2v_p m D(v)) + mg + qm(u-v)$ (4)
- $\varepsilon = \rho_g / \rho_p, \ \rho = \rho_p \alpha; \ n = n(\varepsilon), \ m = m(\varepsilon), \ u = u(\varepsilon), \ v = v(\varepsilon)$
- $D(w) = \frac{1}{2}[grad(w)+(grad(w))^{T}]$

2. Theoretical Analysis and Contribution

Assuming the existence of an indicator that measures the ratio of proportionality between the densities of the two phases, in particular the parameter ε such that $0 << \varepsilon < 1$.

 $\varepsilon = \rho_q / \rho_p, \ \rho = \rho_p \alpha ; \ n = n(\varepsilon), \ m = m(\varepsilon), \ u = u(\varepsilon), \ v = v(\varepsilon).$

When $\varepsilon \rightarrow 0$, result the following mathematical model which is compressible apparently.

 $\partial_t \rho + div(\rho v) = 0$ (5) $\partial_t (\rho v) + div(\rho v \otimes v) + \nabla P = div(\rho D(v)) + \rho g$ (6) $\nabla p_h = -\rho q(\rho)(u - v)$ (7) $div((1 - \rho)u + \rho v) = 0$ (8) $where P = p_c + p_h.$ $D(w) = \frac{1}{2}[grad(w) + (grad(w))^{\mathsf{T}}]$ (9)

- Equation of state
- $p_c(\rho) = \rho^{\gamma o} exp[k\rho/(\rho^* \rho)], \gamma_o \ge 1, 0 \le \rho \le \rho^* < 1 (10)$
- Equation for the drag force between phases:
- $q(\rho) = C_q/(1-\rho)^s$, s > 0, $s \in [1.4, 3.6]$ (11)

- Let Ω_t an open subset of $[R^3_+ \times [0,\infty)]$,
- $\Gamma_0 = \{ \underline{x} = (x_1, x_2, t) \in R^3 / t > 0 \},$ (2.1)
- $\Omega_t = \{ (x_1, x_2, t) \in R^3 / (x_1, x_2) \in \Omega, 0 \le t < \infty \},$ (2.2) $\Omega \subset R^2$
- The problem is to find the volume fraction of particles $\rho \in C^1(\Omega_t) \cap C^0(\Omega_t)$, velocity of the

- solid particles velocity $v \in C^{2,1}(\Omega_t) \cap [C^{1,0}(\Omega_t)]^d$, and gas velocity represented by $u \in [C^{1,0}(\Omega_t)]^d \cap [C^{1,0}(\Omega_t)]^d$.
- The problem is considered hydrodynamic pressure $p_h \in C^{1,0}(\Omega_t) \cap C^0(t)$, from the state equation (5)- (9), to d= 2, d is the dimension of the space of the dependent variables, this vector functions that vary in space and time, which satisfy the system of equations

Conservative Form Two phase Compresible Model

$$\overline{\varphi} = \begin{pmatrix} \varphi_{1} \\ \varphi_{v_{1}} \\ \varphi_{v_{2}} \end{pmatrix} = \begin{pmatrix} \varphi_{1} \\ \varphi_{2} \\ \varphi_{2} \\ \varphi_{3} \end{pmatrix}$$

$$\overline{F}(\overline{\varphi}) = \begin{pmatrix} \left(Pv_{1} \\ p_{c} + \rho v_{1}^{2} \\ \rho v_{1} v_{2} \end{pmatrix} \right) \begin{pmatrix} \rho v_{2} \\ \rho v_{1} v_{2} \\ p_{c} + \rho v_{2}^{2} \end{pmatrix} \end{pmatrix}^{T},$$

$$\overline{G}(\overline{\varphi}) = \frac{2\mu}{3 \operatorname{Re}} \begin{pmatrix} 0 & 0 \\ 2\frac{\partial v_{1}}{\partial x} - \frac{\partial v_{2}}{\partial y} & 2\frac{\partial v_{1}}{\partial y} - \frac{\partial v_{2}}{\partial x} \\ 2\frac{\partial v_{1}}{\partial y} - \frac{\partial v_{2}}{\partial x} & 2\frac{\partial v_{2}}{\partial y} - \frac{\partial v_{1}}{\partial x} \end{pmatrix}$$

$$\overline{S}(\overline{\varphi}) = \begin{pmatrix} 0 \\ \rho\left(\frac{q(\rho)}{1-\rho}\left(M(t) - \frac{\partial p_h}{\partial x}\right) - g_x\right) \\ \rho\left(\frac{q(\rho)}{1-\rho}\left(M(t) - \frac{\partial p_h}{\partial y}\right) - g_y\right) \end{pmatrix}$$

u = 01

If v=(v1,v2)=0

- $\nabla p_c = \rho g$ (colitional pression gradient)
- $\nabla p_h = -\rho q(\rho) u$ (hydrodinamic pression gradient)

- $div((1-\rho)u) = 0$
- $M = ((1-\rho)u)$
- P=0

Contribution 1: Non conservative of the mixture model

 $U(x,y,t) = (u_1 = \rho, u_2 = \rho v, u_3 = \rho u)$

 $R_t + div RU = 0$

$$(RU)_{t} + div(RU \otimes U) + grad(\varepsilon(1-\rho)\frac{p_{g}}{\rho_{g}} + \rho\frac{p_{p}}{\rho_{p}}) =$$

 $div(\varepsilon(1-\rho)\frac{\tau_g}{\rho_g} + \rho\frac{\tau_p}{\rho_p}) - div(\varepsilon(1-\rho)(u-v)\otimes(u-v) + R\vec{g}; R = \rho + \varepsilon(1-\rho); \varepsilon \to 0, R = \rho,$ $0 < \varepsilon = \frac{\rho_g}{\rho_r} <<1$

- Boundary conditions
- $[(1-\rho)u+\rho v)]$. $\mathbf{n} = M > 0 \in C^0(\Gamma_0 \times [0,\infty))$ (2.3)
- $[\rho v]. \mathbf{n} = m_0 \in C^0(\Gamma_0 \times [0, \infty))$ (2.4)
- $[\rho v \otimes v + PI \rho D(v)].\mathbf{n} = 0 \in C^0(\Gamma_0 \times [0, \infty))$

Is this a boundary free problem

- Initial conditions
- $\rho(\underline{x}, 0) = \rho^0(x, y) \in C^0(R^2_+ \times \{0, T\})$ (2.5)
- $v(\underline{x},0) = v^0(x,y) \in [C^0(R^2_+ \times \{0,T\}]^2$ (2.6)

Cauchy problem

Contribution 2: Conditions to solve

$$grad(P_h) = grad(\varepsilon(1-\rho)\frac{p_g}{\rho_g} + \rho\frac{p_p}{\rho_p}) = \frac{1}{Fr}\frac{R}{(1-R)^m}(u-v)$$

$$Slip = (u - v)$$
$$R\vec{g} = \frac{1}{Fr} Rg\begin{pmatrix} 0\\ 1 \end{pmatrix}, M = U + \frac{1 - R}{R} \rho(u - v)$$

div(M) = 0

3. Numerical Analysis

- The work consists of the construction of a numerical model for the quantitative study of the problem. This includes formulation of decoupling techniques. The solution of the variational problem in space-time, singularized the discreta inestability in time during the process computational.
- To overcome this difficulty we have used the Galerkin method with a numerical technique to capture the discontinuities in the Stream Lines Difussion (SD) with finite elements of type P1 + P2 ([5], [6]).

- In the two-dimensional case, after a process dimensionless introducing a vector function of states, thus the Conservative system in variational form convective-diffusive-reactive flow in the domain located in a rectangular geometry region $\Omega = ((0,L)x(0,H))x[0,T)$ Boundary condition: Inlet (imput) and Wall Initial condition: Step
- Stabilization : SD Numerical Method , this is expressed by:

Application: Discretization Stream Diffusion
capturing Method ([3], [6])
Set
$$U(x, y, t^0)$$

 $\phi(v(x, y, t^0)) = v + \delta(v_t + \psi(v))\partial_i v)$
Find: $U_h^n \in \prod_{n=0}^{N-1} H_0^{1+2}(S_n)$
 $B(U, \phi) = L(\phi)$
 $B(U_h, \phi) = \sum_{n=0}^{N-1} \{U_h^n + \partial_R f(U_h^n)\partial_i U_h^{n}i, v^n + \delta(v_t^n + \psi(v^n))\partial_i v^n)\} + (U_+ - U_-, \phi_+) + \int_{\Gamma_n} U_+ \phi_+ dt; U_{+,-} = \lim_{s \to 0^{+,-}} U(x, y, t+s)$
 $L(\phi) = (U^0, \phi_+) + \int_{\Gamma_n} U_+ \phi_+ dt$
 $U_h = \{u_i \in H^{1+2}(\Omega_i^n) / U_K \in P^{1+2}\kappa(x, y), K \in \mathfrak{I}^n\}$

Numerical Resolution: Using COMSOL Multiphysics

• In the two-dimensional case approximates the solution of the problem, then the method Galerkin stabilized stream Difussion (SD) and a difference scheme (BDF) for the variable explicit Capture and temporal discontinuities of singularities in the streamlines of the convective flow, can be improved with a remesh evolutive with $h = \{10^{-4}, 10^{-3}\}$ side length element maximum and minimum and with a resolution of 0.25 of curvature.

4. RESULTS

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Finite Element type P1+P2



Finite Elements, shape function

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Stabilization SD

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Domain fixed CFB

The axial section of the is represented in the XY plane.



Initial mesh



Remeshing finite Element



Pressure isolines



A nozzle



Multiple nozzles



Tiempo=3.86622 Superficie: Fracción volumétrica, fase dispersa Vector: Campo de velocidad, mezcla

Multiple nozzles



Conclusion

- 1. The spectrum of the color palette, particles (red) and only gas flows (blue), a speed minimum fluidization of the results observed with the increase in the flow in bed, manifests a state of suspension caused by the upward flow gas by one and multiple nozzles. This flow creates drag force (inertial force) which balances gravity and terminal velocity which is manifested in the rate of free of the disperse phase.
- 2. The minimum speed is observed when bubbling the first bubble ppears, this is important because it causes the homogenity mixing Solid -Gas.

3. The convergence criteri is obtained when there expansion homogeneous mixture, ie.



References

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• Thank you very much